

IX. ALTERNATIVES TO IMPROVE TIDAL FLUSHING AND WATER QUALITY

The two sub-embayments linked to the Pleasant Bay estuary by culverts (Muddy Creek and Frost Fish Creek) exhibit relatively poor tidal flushing. Based on the previous hydrodynamic modeling (Kelley *et al.*, 2001), it was anticipated that water quality improvements to these systems likely can be achieved through either resizing of culverts or turning upper portions of the coastal embayments into freshwater ponds. Evaluation of potential alternatives is critical to achieve water quality goals, as well as to avoid adverse environmental impacts. The hydrodynamic models utilized to evaluate tidal flushing provide the basis for quantitatively analyzing the effects of various alternatives on tidal exchange. Using the calibrated models for each system, the model grids were modified to reflect alterations in culvert dimensions and/or bathymetry. Once the hydrodynamic simulations were completed, total nitrogen modeling of each scenario was performed to indicate changes in water column nitrogen concentrations.

The following section describes results of the water quality (nitrogen) analysis performed for the Muddy Creek system, and discusses the implications for each alternative for possible improvements to water quality. This alternatives analysis utilized watershed nitrogen loading and benthic flux loads based on values presented previously. In general, offshore nitrogen concentrations in Pleasant Bay of 0.50 mg/L were used for all alternatives modeling of this analysis; however, an evaluation of an alternative boundary condition was evaluated assuming that potential long-term nitrogen load reductions could lower the total nitrogen concentration in Pleasant Bay (the receiving waters).

The alternatives discussed in this Section do not represent recommendations of the Massachusetts DEP or the MEP. They merely represent how the water quality modeling tool can be utilized to assess potential management alternatives. Prior to implementation of any alternative that alters the system hydrodynamics, a complete environmental assessment of potential adverse impacts will be required.

IX.1 MUDDY CREEK HYDRODYNAMIC ALTERNATIVES

The two culverts running under Route 28 at Muddy Creek each have a height of approximately 2.6 feet and a width of 3.7 feet. Since the surface area of Muddy Creek is relatively large, these culverts are not of sufficient size to allow complete tidal exchange between Pleasant Bay into Muddy Creek. This poor tidal exchange contributes to the water quality concerns for the Muddy Creek system, together with the very high watershed nutrient loading to the Creek (>10,000 Kg/yr). In addition, replacement of these culverts will likely be an expensive alternative due to the large roadway embankment overlying the flow control structures.

Due to the elevation of Route 28 in this region, the roadway embankment prevents storm surge from overtopping the road and “shocking” the ecosystem in Muddy Creek with a pulse of higher salinity Pleasant Bay water. Therefore, turning Muddy Creek into a completely freshwater system is a viable alternative. Other alternatives considered include turning a portion of the system to freshwater and enlarging the culverts to improve tidal exchange.

IX.1.1 Alternative 1 – Muddy Creek as a Freshwater System

Gates could be installed on the Pleasant Bay end of the existing culverts to convert the estuarine system to completely freshwater. As mentioned above, the Route 28 embankment

prevents floodwaters from overtopping the road; therefore, the freshwater ecosystem would remain stable during severe conditions. The gates only would allow unidirectional flow from Muddy Creek into Pleasant Bay. Periodic maintenance of the culvert gates would be required, due to their open exposure within Pleasant Bay. A potential environmental drawback to this alternative is the loss of salt marsh that exists within approximately the northern third of the estuary. In addition, benthic analysis indicated that the region immediately upstream of the culverts contains softshell clam resources. Due to potential damage to benthic and wetland resources, it is anticipated that this alternative is not a viable option.

IX.1.2 Alternative 2 – Muddy Creek as a Partial Freshwater System

To preserve the salt marsh and softshell clam resources in the lower portion of Muddy Creek and improve tidal flushing characteristics without altering the culvert configuration, a dike could be placed approximately $\frac{1}{2}$ mile upstream from the roadway embankment (see Figure IX-1). The region upstream of the dike would be maintained as a freshwater pond, again with a gate that only allowed unidirectional flow from the upper portion of Muddy Creek to the lower estuarine portion. Since the poor tidal exchange through the existing culverts is caused by the small cross-sectional area of the culverts relative to the surface area of Muddy Creek estuary, reducing the estuarine surface area will improve flushing characteristics. For example, hydrodynamic model simulations of dike placement as shown in Figure IX-1, reduces the mean-tide estuarine volume by 55%; however, it causes very little reduction in tidal prism (Kelley *et al.*, 2001).

Total nitrogen modeling of the split system required assumptions regarding potential attenuation of nitrogen within the upstream freshwater section. Due to the relatively short retention time of water (~11 days) in this upper portion, resulting from the large volume of groundwater flow entering this portion of the system, it was anticipated that a moderate attenuation of nitrogen would occur in the freshwater portion. Using modest estimates of a 40% reduction in the watershed and sediment loading in the freshwater portion, the modeled reduction in nitrogen concentration for both the existing and Alternative 2 conditions is shown Figures IX-2 and IX-3, respectively. Based on these results, a significant reduction in total nitrogen would occur in the lower portion of Muddy Creek as a result of this alternative.

As described in Kelley *et al.* (2001), design considerations for the dike should include sufficient elevation to minimize potential overtopping during storm conditions. In addition, the freshwater pond level should be set at least 1 ft above the anticipated mean tide level in the estuarine section (about 3.5 feet NGVD according to the hydrodynamic modeling) to ensure flow exits the freshwater section during all phases of the tide. A simple adjustable weir could be designed to fine-tune the water elevation in the freshwater section.

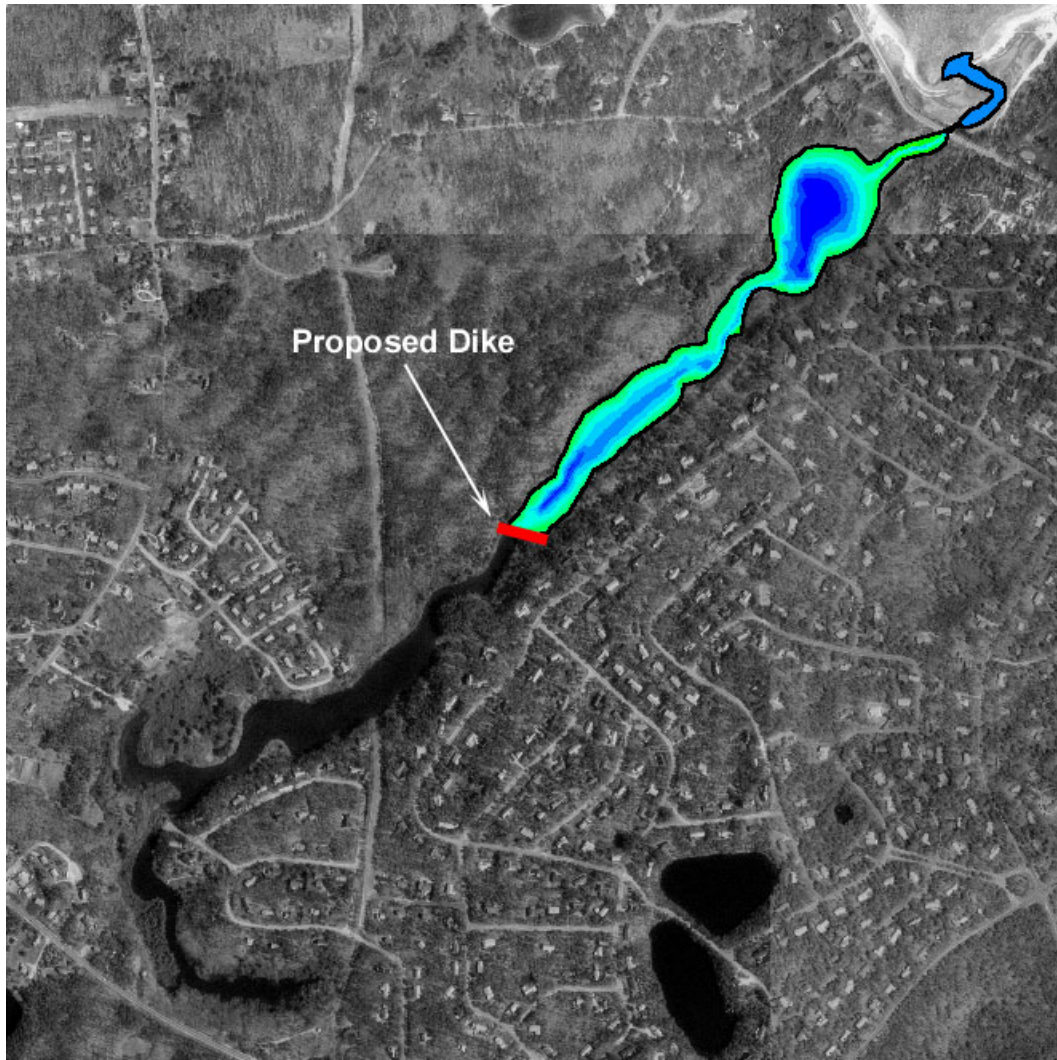


Figure IX-1. Muddy Creek Alternative 2 illustrating the approximate position of the dike separating the freshwater and brackish regions.

IX.1.3 Alternatives 3 and 4 – Increase Size of Route 28 Culverts

Although the Muddy Creek culverts are in good structural shape, it is possible that the Massachusetts Highway Department would consider culvert upgrading as part of the planned Route 28 improvements, if it clearly can be demonstrated that larger culverts are necessary to improve water quality. To assess tidal flushing improvements associated with larger culverts, two alternative culvert sizes were considered: a width of 8 feet and a width of 16 feet. Unlike the existing culverts, the culverts would be designed with a height similar to the tide range in Pleasant Bay (approximately 4.5 feet) to prevent the additional frictional drag associated with totally submerged culverts.

Based on the hydrodynamic modeling results (Kelley *et al.*, 2001), the residence time for Alternative 3 is similar to existing conditions, since the tidal prism increases by only about 20% and the mean-tide volume remains similar. Therefore, the decrease in residence time resulting from this Alternative was about 17%. The larger culvert alternative (Alternative 4) provided a significantly larger tide range, but a similar residence time to Alternative 2.

Although both alternatives 3 and 4 provide significantly better water exchange between Pleasant Bay and Muddy Creek, improvements to average total nitrogen concentrations resulting from the larger culverts are negligible. Figures IX-4, IX-5, and IX-6 illustrate the relative changes in average nitrogen concentrations for existing, 8 ft wide culvert, and 16 ft wide culvert, respectively. Due to a net decrease in the mean volume of Muddy Creek resulting from better flushing characteristics, the nitrogen load potentially could become more concentrated in much of the embayment. A balance between improved flushing and decreased sub-embayment volume governs the mean total nitrogen concentrations. As a result, for both 3 and 4, N concentrations in the lower pond do not change from present conditions. Only for alternative 4 is there a change in the N concentrations of upper portion of the pond of approximately 0.1 mg/L. Therefore, total nitrogen modeling shows that the culvert alternatives as configured will not significantly improve water quality, even though flushing in the upper portion of the creek is improved, hence these alternatives should not be considered further in the future.

IX.2 MUDDY CREEK NITROGEN LOADING ALTERNATIVES

Due to the hydrodynamic simplicity of Muddy Creek, this system allowed rapid analysis of several nitrogen loading alternatives. The sensitivity of the model results to a range of different nitrogen loading scenarios, as well as alternate boundary conditions, were evaluated in the context of the water quality model. Similar to all previous modeling scenarios described, benthic flux was dependent on the overall sub-embayment nitrogen load, where a linear relationship exists between the nitrogen load derived from external sources and the benthic regeneration.

Including the three original modeling scenarios (existing conditions, build out, and no anthropogenic load), a total of 14 water quality modeling scenarios were evaluated. A summary of the nitrogen loading and water quality modeling results from these scenarios is shown in Tables IX-1 and IX-2. Based on the results of this analysis, several alternatives show promise with regards to nitrogen load reduction including Alternative E (3,000 kg/year reduction in upper watershed) and Alternative N (50% reduction in watershed load). Figures IX-7 through IX-10 illustrate the results of selected alternatives for the Muddy Creek system. Based on the results of the modeling, both reducing the load to the upper watershed and bifurcating the estuarine system (making the upper portion freshwater) will improve the overall water quality.

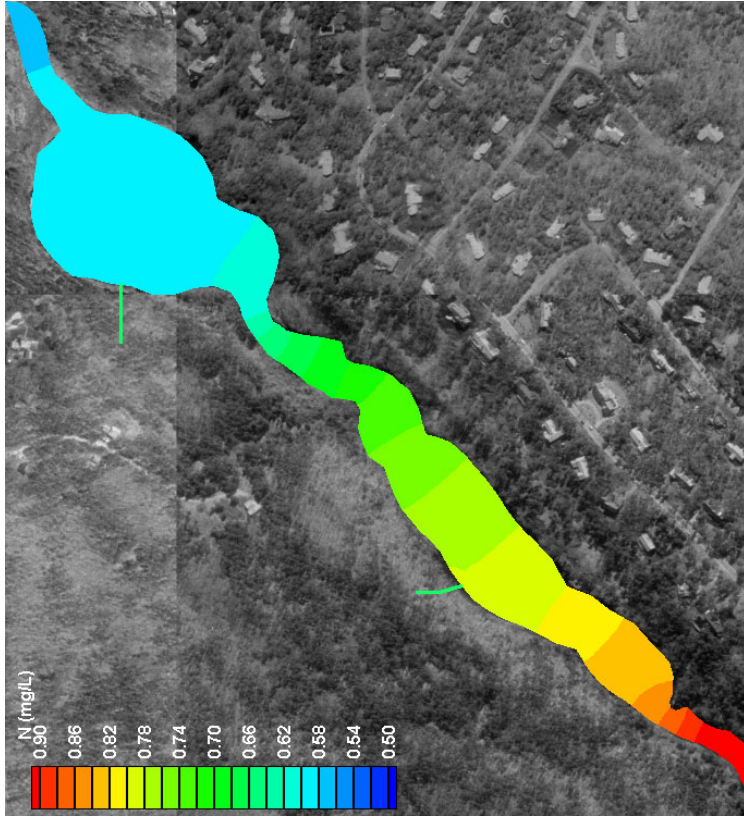


Figure IX-2. Close up of the lower portion of Muddy Creek showing total nitrogen concentration contours for modeled present conditions.

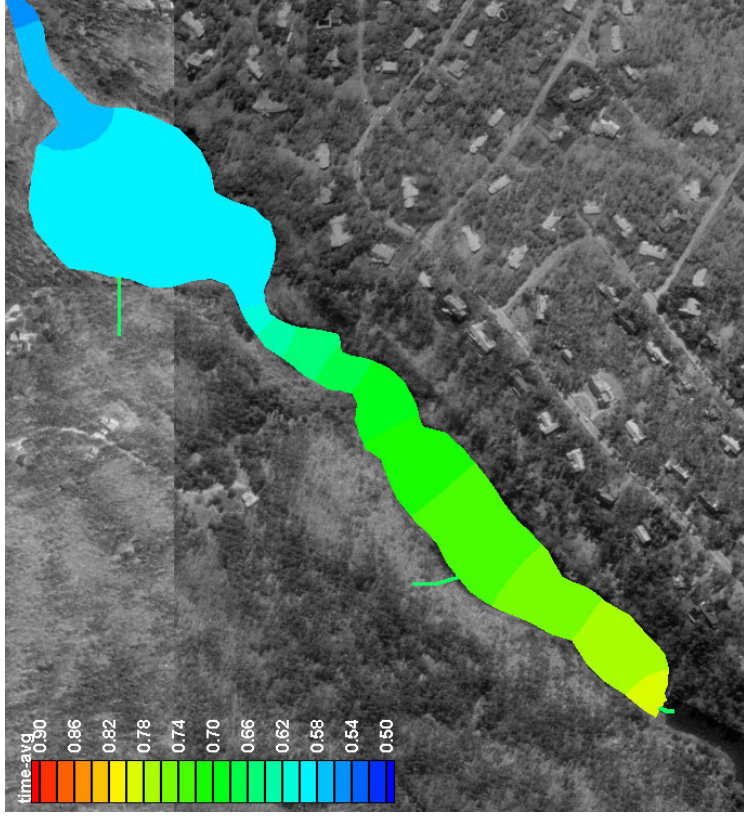


Figure IX-3. Muddy Creek total nitrogen concentration contours for Flushing Alternative 2, where the upper portion of the creek is turned into a freshwater system by the construction of a dike approximately ½ mile upstream of the route 28 roadway embankment.

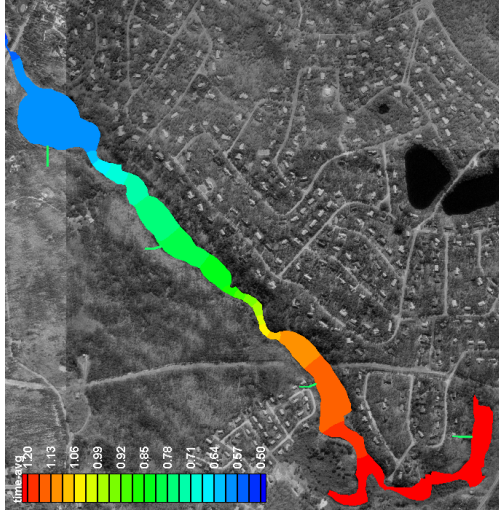


Figure IX-4. Contour plot of modeled present conditions for Muddy Creek, showing total nitrogen concentrations.

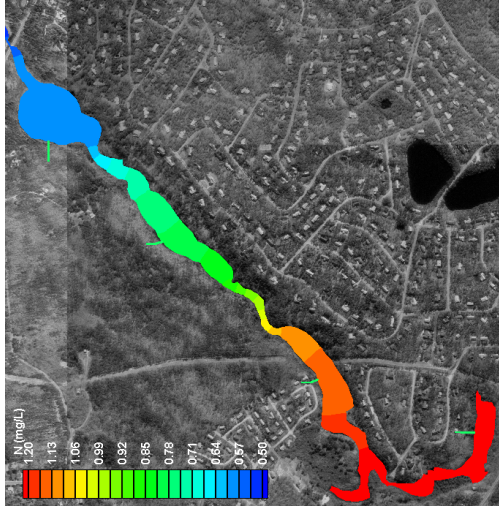


Figure IX-5. Contour plot of total nitrogen concentrations for Muddy Creek flushing Alternative 3, an 8 ft wide box culvert replacement for the existing Route 28 culverts.

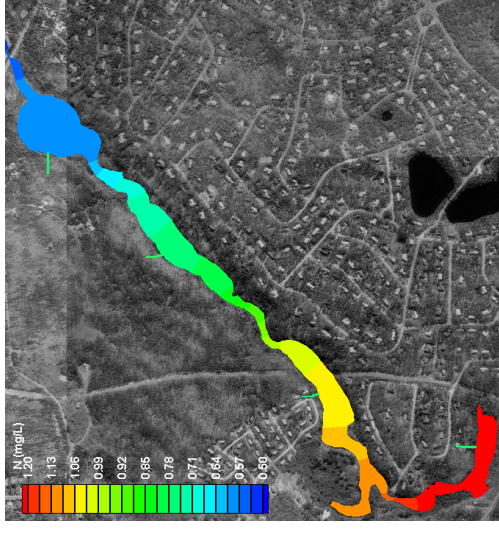


Figure IX-6. Contour plot of total nitrogen concentrations for Muddy Creek flushing Alternative 4, a 16 ft wide box culvert replacement for the existing Route 28 culverts.

Table IX-1. Alternative water quality scenarios run for the Muddy Creek system, including scenarios which modify the hydrodynamics of the system (g, h, i) for present loading conditions, and others that demonstrate the relative impact of load reductions in different areas of the system (i.e., lower creek vs. upper creek, as in e and f).

sub-embayment	watershed load (kg/day)	atmos. deposition (kg/day)	benthic flux (kg/day)	sub-embayment	watershed load (kg/day)	atmos. deposition (kg/day)	benthic flux (kg/day)
a) Present				h) Alt3			
MC-lower	13.36	0.21	-1.88	MC-lower	13.36	0.21	-1.88
MC-upper	19.05	0.20	4.69	MC-upper	19.05	0.20	4.69
b) Build out				i) Alt4			
MC-lower	14.24	0.21	-2.14	MC-lower	13.36	0.21	-1.88
MC-upper	22.69	0.20	5.34	MC-upper	19.05	0.20	4.69
c) No Anthropogenic Load				j) Alt2: no anthropogenic load			
MC-lower	0.50	0.21	-0.10	MC-lower	0.50	0.21	-0.08
MC-upper	0.87	0.20	0.25	MC-upper	0.44	0.20	0.09
d) Present Loading -alternate boundary condition (0.4 mg/L)				k) Alt2: no load w/alt boundary condition (0.40 mg/L)			
MC-lower	13.36	0.21	-1.88	MC-lower	0.50	0.21	-0.08
MC-upper	19.05	0.20	4.69	MC-upper	0.44	0.20	0.09
e) 3000 kg/yr reduction in upper watershed				l) Alt2: 3000 kg/yr reduction in upper watershed			
MC-lower	13.36	0.21	-1.41	MC-lower	13.36	0.21	-1.16
MC-upper	10.83	0.20	3.52	MC-upper	6.42	0.20	0.97
f) 3000 kg/yr reduction in lower watershed				m) Alt2: 3000 kg/yr reduction in lower watershed			
MC-lower	5.15	0.21	-1.41	MC-lower	5.15	0.21	-0.97
MC-upper	19.05	0.20	3.52	MC-upper	11.35	0.20	2.82
g) Alt2: (40% attenuation of upper ws)				n) 0.55 mg/L threshold with 0.50 mg/L BC 50% ws load reduction)			
MC-lower	13.36	0.21	-1.44	MC-lower	6.58	0.21	-0.94
MC-upper	11.35	0.20	2.82	MC-upper	9.43	0.20	2.35

Table IX-2. Comparison of model average total N concentrations from present loading and build out scenario, with percent change, for Muddy Creek water quality alternative scenarios shown in Table IX-1.

sub-embayment	present N conc. (mg/l)	alternative N conc. (mg/l)	percent change (mg/l)	sub-embayment	present N conc. (mg/l)	alternative N conc. (mg/l)	percent change (mg/l)
b) Build out				h) Alt3			
MC-lower	0.60	0.61	2.4%	MC-lower	0.60	0.60	-0.1%
MC-upper	1.21	1.32	9.9%	MC-upper	1.21	1.21	0.3%
c) No Anthropogenic Load				i) Alt4			
MC-lower	0.60	0.50	-16.2%	MC-lower	0.60	0.59	-1.4%
MC-upper	1.21	0.53	-55.7%	MC-upper	1.21	1.11	-8.0%
d) Present Loading -alternate boundary condition (0.4 mg/L)				j) Alt2: no anthropogenic load			
MC-lower	0.60	0.50	-15.9%	MC-lower	0.60	0.50	-16.4%
MC-upper	1.21	1.11	-7.9%	MC-upper	1.21	-	-
e) 3000 kg/yr reduction in upper watershed				k) Alt2: no load w/alt boundary condition (0.40 mg/L)			
MC-lower	0.60	0.55	-7.4%	MC-lower	0.60	0.40	-32.3%
MC-upper	1.21	0.67	-44.0%	MC-upper	1.21	-	-
f) 3000 kg/yr reduction in lower watershed				l) Alt2: 3000 kg/yr reduction in upper watershed			
MC-lower	0.60	0.57	-3.9%	MC-lower	0.60	0.55	-7.2%
MC-upper	1.21	1.13	-6.1%	MC-upper	1.21	-	-
g) Alt2: (40% attenuation of upper ws)				m) Alt2: 3000 kg/yr reduction in lower watershed			
MC-lower	0.60	0.58	-2.5%	MC-lower	0.60	0.56	-5.9%
MC-upper	1.21	-	-	MC-upper	1.21	-	-
				n) 0.55 mg/L threshold with 0.50 mg/L BC 50% ws load reduction)			
				MC-lower	0.60	0.49	-18.4%
				MC-upper	1.21	-	-

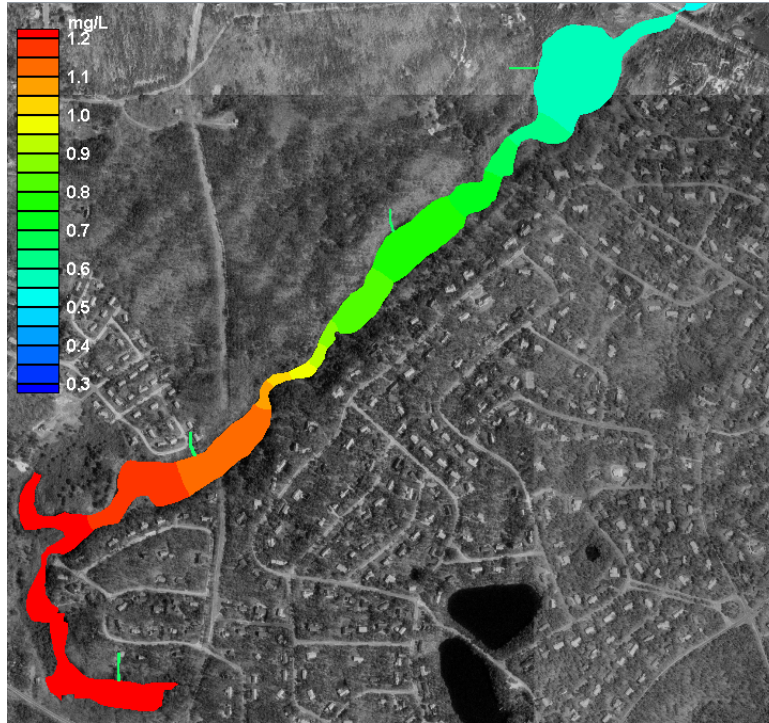


Figure IX-7. Scenario A: Contour plot of modeled total nitrogen concentrations in Muddy Creek, for present loading conditions, and present total nitrogen concentration in Pleasant Bay (0.50 mg/L).

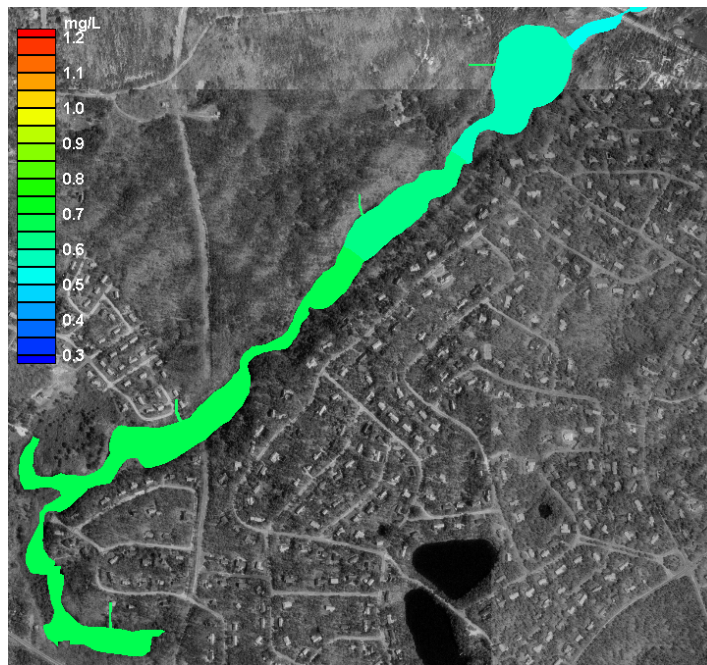


Figure IX-8. Scenario E: Contour plot of modeled total nitrogen concentrations in Muddy Creek, for present loading conditions, with 3000 kg/yr reduction in the load to the upper creek watershed, and present total nitrogen concentration in Pleasant Bay (0.50 mg/L).

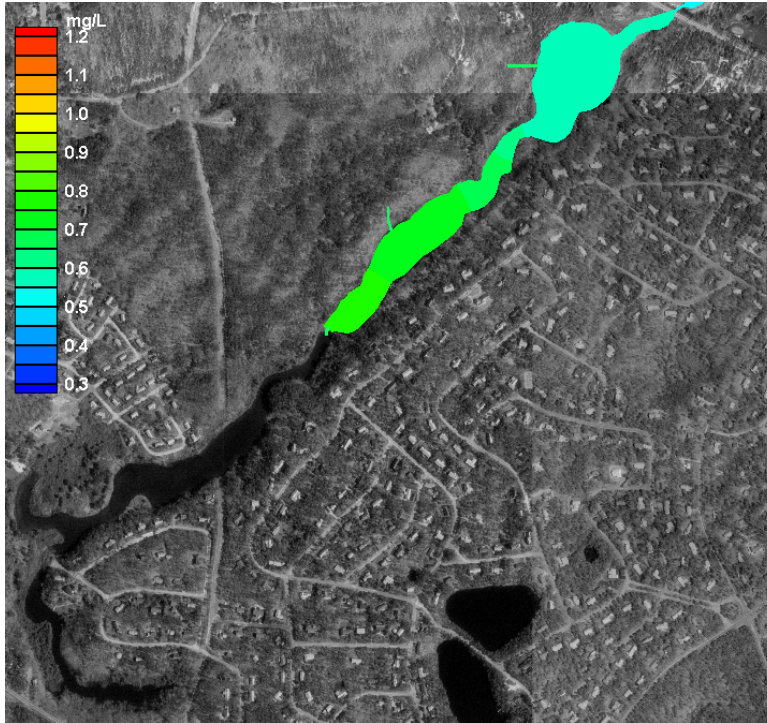


Figure IX-9. Scenario H: Contour plot of modeled total nitrogen concentrations in Muddy Creek, for present loading conditions, and alternate fresh water configuration of the upper creek (alternative 2), with present total nitrogen concentration in Pleasant Bay (0.50 mg/L).

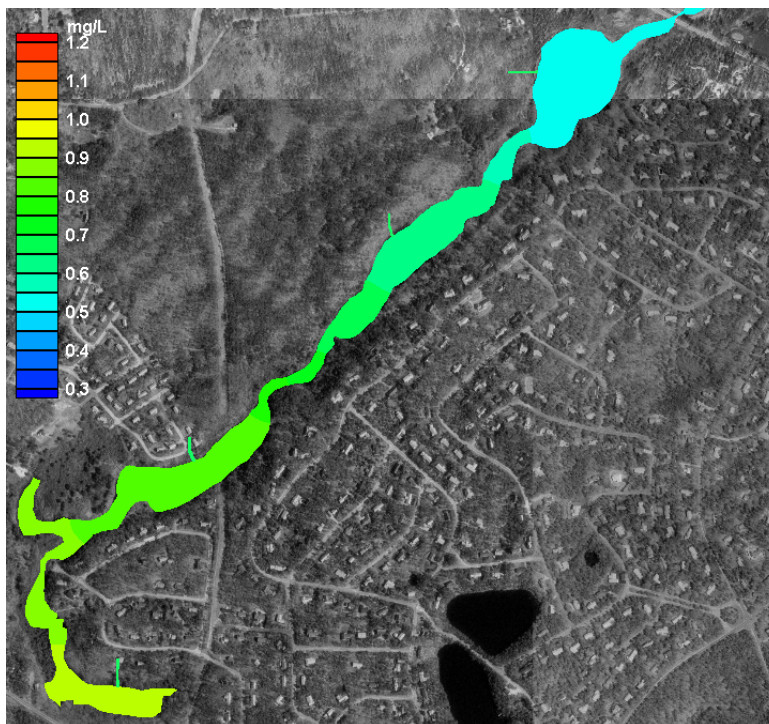


Figure IX-10. Scenario N: Contour Plot of modeled total nitrogen concentrations (mg/L) in the Muddy Creek system, for threshold loading conditions (0.55 mg/L in lower Muddy Creek), and present background N concentration at the entrance to Pleasant Bay (0.50 mg/L). 50% watershed load reduction is required to achieve target N concentration in lower Muddy Creek.